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A systematic review of nature-positive climate risk transfer and financing instruments

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Nature-based solutions can strengthen climate resilience, but they remain underfinanced. Innovative financial instruments that transfer or reduce climate risk while enhancing ecosystem services help close the adaptation and nature finance gaps. Here we synthesize evidence on nature-positive climate risk transfer and financing instruments, with attention to how the effectiveness and economic viability of supported nature-based interventions are reported. We screened ~3,200 academic publications and 78 institutional databases, identifying 33 distinct nature-positive financial instruments. We introduced a typology that organizes them by financial instrument category. This typology, alongside a global database of 313 projects found in the literature and an inventory of 76 implemented projects, supports replication, adaptation, and scaling of nature-based solutions in diverse contexts. The systematic review highlights evidence gaps, including limited equity considerations and uncertainties in risk modeling. Together, the typology, inventory, and synthesis provide a foundation for advancing nature-positive finance through future research, investment, and policy design.

Five of the ten most severe risks in the next decade are environmental, according to the Global Risk Report 2026[1], with extreme weather events, biodiversity loss and ecosystem collapse, and critical changes to Earth systems ranking as the top three.

Nature-based Solutions (NBS) for climate resilience offer great opportunities to address the crises of climate change, biodiversity loss, and land degradation in an integrated way. NBS are "actions to protect, conserve, restore, sustainably use and manage natural or modified […] ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits"[2]. The term NBS is an umbrella term including other approaches like ecosystem-based mitigation, ecosystem-based adaptation, and ecosystem-based disaster risk reduction[3]. NBS for climate resilience aim to reduce climate and disaster risk by regulating at least one climate-related hazard. Examples include the protection of mangroves, which attenuate wave energy and protect coastal communities[4], and the preservation of forests, which reduce flood volumes and protect adjacent agricultural fields[5]. Compared to gray infrastructure, NBS can address a broader range of societal challenges beyond disaster risk, including climate change, food security, water security, human health, and social and economic development[3].

Given their potential to regulate climate risks and address multiple societal challenges[6,7], NBS have gained substantial attention in global policy discussions. International agreements like the Sendai Framework for Disaster Risk Reduction 2015–2030[8], the Agenda 2030 for Sustainable Development[8], the Paris Agreement[9], and the Kunming-Montreal Global Biodiversity Framework[10] acknowledge the need to advance NBS and climate risk finance. Over 80% of the updated Paris Agreement climate pledges include NBS[11]. However, despite the political pledges, the nature and climate finance gaps remain large.

Global investments in NBS amounted to about USD 200 billion per year in 2022, with public funds accounting for 82% and private finance for 18%. However, investments would need to nearly triple to USD 542 billion by 2030 to achieve climate, biodiversity, and land degradation neutrality targets[12]. Low- and middle-income countries are especially challenged to protect, manage, and restore natural assets with limited budgets. In 2022, finance flows to NBS accounted for only one percent of the total Overseas Development Assistance[12]. In February 2025, governments worldwide agreed to mobilize USD 200 billion annually by 2030 - including USD 30 billion in international flows - to achieve the goals of the Global Biodiversity Framework[13].

Research on constraints to NBS implementation found that financing of NBS is a central barrier and advocated for systematic reviews on this

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topic[14]. A systematic review of systematic reviews on NBS for climate adaptation identified NBS financing as a key research gap, also finding little evidence on "social issues" and "the role(s) of the private sector"[15]. Recognizing this research gap, the European Commission created a task force titled 'business models and financing for NBS' as one of four task forces on NBS under the Horizon 2020 program[16].

A scoping review defined alternative financing (AF) models for NBS as "arrangements that draw on financial resources other than public budgets collected through general taxation"[17]. It proposed a typology classifying AF models, among others, based on who finances and who funds them. The review emphasized that drivers and barriers associated with AF for NBS depend on the broader political, economic, social, technological, legal, and environmental context of NBS, resulting in a need to address these aspects in parallel to successfully finance NBS. It called for a systematic assessment of existing AF models and their context to understand their state of development, local applicability, and scalability[17]. The review identified "NBS monitoring, quantification, valuation, and monetization" as a gap in NBS financing research[17].

Reviews of finance for urban NBS[18] and NBS in Europe[19] have identified valuation and accounting of NBS benefits and effectiveness, along with coordination across public and private financiers and reliance on public resources, as key financing barriers and challenges to NBS implementation. They advocated for private sector involvement in NBS financing "through (innovative) economic and financial instruments"[19] and recommended "a systematic review on the sources of finance for (different types of) NBS" across ecological domains, considering valuation and accounting methods for NBS benefits[18]. Recent reviews continue to recognize the potential of innovative and AF mechanisms for NBS involving insurers and the private sector and identify it as a research gap[20].

A systematic review of 155 articles found that the public sector is the primary financing source of NBS for reducing disaster risk[21]. The authors concluded that "a transformative upscaling of NBS [for disaster risk reduction] will require innovative financing strategies, involving the private sector"[21]. While previous studies provide examples of innovative schemes that combine insurance and risk reduction[22], no systematic review exists on instruments that combine insurance with 'nature-based' risk reduction. Research has also explored innovation in financing NBS for specific ecosystems, regions, and hazards, such as NBS in European and North American cities[16,19,23,24], in coastal areas[25], and agrifood systems[26]. NBS for climate resilience are particularly well-suited to innovative risk transfer and financing solutions due to their hazard-regulating benefits, but no review has systematically organized the evidence on their financing.

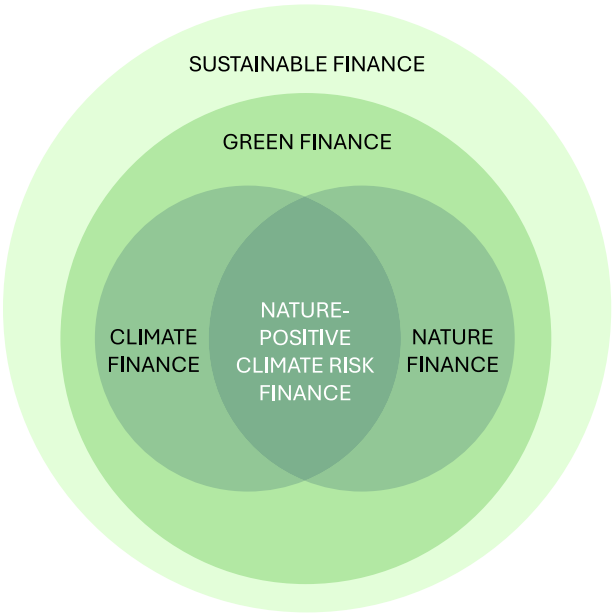


Fig. 1 | Nature-positive climate risk financing in the broader finance landscape. Figure adapted from World Bank[64] with permission. Nature-positive climate risk finance falls under green finance, a subset of sustainable finance. Unlike conventional finance, sustainable finance considers environmental, social, and governance factors. Green finance encompasses climate finance, including mitigation, adaptation, and climate risk finance, and nature finance, defined as all finance flows to NBS[12]. Nature-positive climate risk finance is at the intersection of climate finance and nature finance.

The present systematic review addresses the described research gaps by structuring the evidence on nature-positive climate risk finance, a subset of green finance, at the intersection of climate and nature finance (Fig. 1). The review covers all ecosystems, geographies, and climate-related hazards as well as academic and non-academic (also called gray) literature. The scope of the research is specified by the Population, Intervention, Subject, Comparators, and Outcomes (PISCO) scope elements (see Supplementary Table 4), which extend the commonly used PICO tool for systematic reviews[27].

This review focuses on nature-positive climate risk transfer and financing instruments (CRTFIs, hereafter also referred to as financial instruments), defined as mechanisms where a part of the disaster risk is transferred to or financed by another party (that does not hold the risk initially) and that mitigate climate-related hazards through NBS. CRTFIs implicitly or explicitly redistribute risk between the parties involved. In contrast to AF models that support all NBS, CRTFIs support NBS for climate resilience.

Nature-positive investments, more broadly, have been defined as "financial resources committed to activities which explicitly and measurably maintain or enhance the integrity of ecosystems against a defined baseline - or create the enabling conditions for doing so"[28]. The term nature-positive emerged with the Global Goal for Nature, aiming to end and reverse nature loss by 2030 on a 2020 baseline, and reach full recovery by 2050[29]. While the goal focuses on biodiversity, it also encompasses a people-positive vision, recognizing that ecosystem health relies on social inclusion and equity.

A scoping review on financing NBS and social equity in the U.S. found that NBS benefits vary by race, ethnicity, income, and cities' financial capacity to invest[30]. It noted that most studies assess financial instruments and ecosystem services separately, underscoring the need for research that examines both jointly. The authors emphasized that local context, processes, and financial instruments affect the distribution of NBS costs and benefits[30]. A review of academic studies published from 2000 to 2021 that present an economic appraisal for NBS found that 30% of the studies considered equity. About 30% of the reviewed studies incorporated a social justice lens, assessing preferences about NBS or benefits of NBS for different income groups. Fewer studies, often those using stated preference methods, compared results by gender (20%) as well as race and ethnicity (8%)[21]. Risk reduction interventions such as NBS and CRTFIs inherently affect the distribution of risks and benefits across populations. Without attention to equity, such interventions may unintentionally reinforce existing inequalities. For example, investors might prioritize well-resourced neighborhoods while more vulnerable areas are overlooked[31]. The present literature lacks a systematic assessment of outcome equity considerations associated with nature-positive CRTFIs.

The objective of this review is to structure the evidence on nature-positive CRTFIs, including how the effectiveness and economic viability of the supported NBS are reported and assessed in the academic and non-academic English-language literature. The review also aims to create an inventory of nature-positive CRTFIs that were either under implementation or implemented at the time the collected material was published. The review answers the following questions:

1. What are the risk transfer and financing instruments to support Nature-based Solutions (NBS) for climate resilience?
2. How are the NBS that these instruments support evaluated with respect to hazard regulation benefits (including the use of probabilistic analyses, reporting of uncertainties in the benefit estimation, and

consideration of outcome equity), other co-benefits (ecosystem services and broader social and ecological outcomes), and economic appraisals?

Uncertainty is a central feature of climate risk management planning. Including uncertainty as a review criterion allows us to assess whether and how decision-making processes acknowledge limitations in knowledge, and plan for a range of future conditions. Including outcome equity as a review criterion enables us to assess whether NBS projects consider who benefits and who might be left behind. Considering distributional outcomes helps ensure that the NBS' hazard regulation and co-benefits reach those most in need.

Key contributions of the review include a typology that organizes the identified 33 distinct CRTFIS by financial mechanism and an inventory of 76 implemented projects that support replication, adaptation, and scaling of NBS for climate resilience. The review highlights evidence gaps, including limited consideration of equity and uncertainties in risk modeling.

Results

Nature-positive climate risk transfer and financing instruments

The review identified 33 distinct nature-positive CRTFIs, which are described in Table 1 and Supplementary Table S15. Figure 2d illustrates the breadth of CRTFIs, which target different ecosystems through a range of nature-based interventions (Fig. 2c). Instruments can be grouped into seven categories: risk transfer instruments (59% of instruments), debt instruments (24%), performance-based instruments (5%), credit enhancements (4%), agri-environmental schemes (3%), actively managed funds (2%), and market instruments like carbon and resilience credits (2%) (Fig. 2a).

Each CRTFI instrument group has unique characteristics: 1. Risk transfer instruments transfer risks between at least two parties, which can take the form of a payment transaction (like an insurance scheme) or a contract. 2. Debt instruments involve the transfer of funds to another party that must repay them later, typically with interest[32]. These instruments include government or corporate bonds, repayable loans to fund NBS, and debt-for-nature swaps. 3. Credit enhancement instruments improve the credit rating of the borrower, e.g., through a construction all risks insurance for an NBS project, a credit guarantee that covers overdue loan repayments, a guarantee, fund, or political risk insurance to cover defaulting green bonds, and a catastrophe wrapper that is triggered by a hazard-related threshold to cover repayments of debt to fund NBS (like a wind speed-triggered catastrophe wrapper covering blue bond repayments in case of a tropical cyclone). 4. Performance-based instruments are contracts that link funding to verifiable social and environmental outcomes through financial incentives and/or penalties. For example, an environmental impact bond may tie its yield to the stormwater runoff reduction achieved by an NBS; and innovative payments-for-ecosystem-services schemes and environmental cash-for-work programs compensate contributions to NBS. 5. Agri-environmental schemes compensate farmers for any loss of income linked to NBS implementation[33]. Examples include conservation easements (permanent conservation requirements on agricultural land), fallowing agreements (e.g., temporary provision of farmland for floodwater storage), cropland retirement programs (a temporary retirement of erodible farmland), and tax benefits for conservation agriculture. 6. "Equity instruments: Actively managed funds" are "funds where an investor is tracking the performance of an investment portfolio and making buy, hold, and sell decisions about the assets in it"[34]. Examples include water funds, prescribed fire catastrophe funds, and disaster risk reduction funds capitalized with insurance premiums. 7. Market instruments include resilience and carbon credits to fund NBS, insurance for these credits, and forest carbon offset buffer pools covering various risks.

We compiled an inventory of 76 projects that were either under implementation or implemented at the time the collected material was published. A map showing the projects in the inventory is accessible at https://ri-cities.github.io/nbs_finance/. The inventory comprises 27 unique types of CRTFIs; and Table 1 encompasses six additional CRTFIs that were only at the conceptual stage, meaning that these instruments have been identified in the literature as applicable for investments in NBS that regulate climate-related hazards but have not yet been implemented for that purpose. Figure 3 shows the geographic distribution of projects in the inventory, which evinces a bias toward North America in the reviewed English-language publications. Supplementary Fig. 1 shows the distribution of instrument groups per global region.

Nature-positive CRTFIs began to emerge in the academic literature from 2011 onwards and have gained considerably more attention since 2019 in both academic and non-academic literature (Supplementary Fig. 2). Projects are proposed or implemented nature-positive CRTFIs identified in the literature. In contrast to the inventory (which is limited to projects for which implementation has started), the project database contains projects at all development stages at the time the collected material was published. The dataset is publicly available[35]. Most projects were in the implementation phase (42% of academic and 62% of non-academic projects) or the conceptual phase (10% of academic and 31% of non-academic projects) (Supplementary Fig. 3). Regarding the geographic scale, we found that most projects and assessments were conducted at the landscape scale (e.g., a river basin, forest, or coral reef) (30%) and national (27%) scale, followed by global projects (11%), regional projects covering multiple countries on a single continent (10%), and projects at the subnational scale (10%) (Supplementary Fig. 4). An assessment of project locations showed that the evidence in English-language publications is concentrated in North America (34% of all projects) as well as Latin America and the Caribbean (26%), reflecting the focus on the U.S. National Flood Insurance Program and reef insurance (Supplementary Fig. 5). Most first authors are based in the U.S. (116), followed by the United Kingdom (25), Switzerland (21), France (9), and Germany (9) (Supplementary Fig. 6).

NBS targeted by CRTFIs

Evidence of NBS finance exists across all ecosystem categories, with a slight dominance of marine and coastal ecosystems, especially reef ecosystems. Of all the ecosystems financed by nature-positive CRTFIs found in this review (Supplementary Fig. 7), 46% are coastal and marine ecosystems, 28% terrestrial, and 23% freshwater ecosystems (Fig. 2b and Supplementary Fig. 8).

Coral reefs are the ecosystem most frequently supported by nature-positive CRTFIs found in the review (28%), followed by rivers and floodplains (20%), mangrove forests (17%), forests (13%), cultivated areas (12%), and urban/semi-urban areas (12%) (Supplementary Fig. 8).

Overall, there is no clear trend in the preferential use of risk transfer and finance instruments per ecosystem. As shown in Fig. 2c, CRTFIs to scale up NBS for food production receive less attention than actions to restore, protect, and manage ecosystems. While management also has a relatively low frequency, the actual frequency is higher as interventions classified as combinations include NBS that mix management, protection, and restoration (Fig. 2c). In the Sankey diagram (Fig. 2c), double counting of projects occurs when one of the three assessed variables (financial instrument, ecosystem, or nature-based intervention) has more than one value, e.g., when a blue bond supports the protection of forests, mangroves, and mooreland[36].

The most frequent hazards addressed by NBS are coastal hazards such as coastal flooding, storm surge, and cyclones, which are mentioned in over half of the publications (54%). Fluvial and flash floods (32%) were the second most mentioned hazard, followed by erosion (18%). Wildfire, drought, wind/storm, and sea level rise each appeared in over 10% of the publications (Supplementary Fig. 9). There is also no clear trend in the preferential use of risk transfer and finance instruments per hazard. The Sankey diagram reflects the large representation of reef and nature-positive fluvial flood insurance in the evidence (Supplementary Fig. 10).

Prominent examples of nature-positive climate risk transfer instruments

The two CRTFIs most prominently reported in the reviewed literature were ecosystem insurance and nature-positive resilience insurance, each

Table 1 | Nature-positive risk transfer and financing instruments (for more details and references, see Supplementary Table 15)

CRTFI	Definition	Example	Implementation ongoing or completed
Risk transfer instruments			
Ecosystem insurance	Ecosystem insurance (or natural asset insurance) is a contract, in which a policyholder pays a fixed amount (the premium) to an insurer in exchange for reimbursements to restore natural asset (e.g. a coral reef) following a covered event (e.g. a tropical cyclone).	Quintana Roo reef insurance and Mesoamerican reef insurance against hurricanes (see Table 3 for more examples)	Yes
Nature-positive resilience insurance	Resilience insurance incentivize an investment in risk reduction through a premium discount. Nature-positive resilience insurance is an insurance scheme that grants the policyholder a premium discount in return for nature-based interventions that regulate a climate-related hazard.	U.S. National Flood Insurance Program	Yes
NBS as prerequisite for subsidies/assistance	NBS can be a prerequisite to access insurance subsidies and other assistance payments. The requirements apply to the individual level or the community level.	Requirement to comply with floodplain regulations to join the U.S. National Flood Insurance Program; Requirement to restore ecosystems after wildfires to get property insurance in Australia	Yes
Insurance payouts used to fund NBS	Insurance payouts can be used to fund NBS, e.g. through property insurance coverage enhancements (providing increased payouts when green designs are used in the repair and reconstruction process) and supplemental coverage (an additional layer of coverage providing funding for an NBS in the repair and reconstruction process).	AXA XL's green building enhancement program in the U.K. (could be extended to finance NBS)	Yes
Bundling agricultural insurance & NBS	Bundling resilient seeds with insurance reduces insurance premiums and increases the demand and the area of insurance coverage. Paying premium contributions through ecosystem conservation activities is another way of bundling agricultural insurance and NBS.	Pilot in Nicaragua allowing smallholder farmers to pay agricultural insurance premiums through conservation; Bundling of insurance with drought-resilient seeds in India and Bangladesh	Yes
Prescribed fire liability insurance	A prescribed fire is an intentional fire used to reduce wildfire hazard and conserve biological diversity. A prescribed fire insurance covers a fire managers' liabilities for property damage and human injury due to escaped prescribed fires and smoke intrusion.	Insurance coverage offered by prescribed burn associations in the U.S.	Yes
Debt instruments			
Green bond*	Bonds are fixed-income securities that raise capital for projects with environmental outcomes[64]. A bond issuer owes a bond holder a debt that is repaid with a predefined interest by a fixed date. The bond investor (or bond holder) provides financial capital ('proceeds') to the bond issuer who invests in the green project. The issuer transfers regular interest payments ('coupons') to the investor until the bond matures and the issuer repays the entire initial investment (the 'principal').	North-Rhine Westphalia state bank's green bond to restore the Emscher river in Germany; German federal government's €17.25bn 2023 green bond that spent 4% of proceeds on NBS for climate resilience	Yes
Blue bond*	Blue bonds are fixed-income securities that raise capital from impact investors for "marine and ocean-based projects that have positive environmental, economic, and climate benefits"[65].	First sovereign blue bond issued in the Seychelles in 2018; Nordic-Balitic Blue Bond launched in 2019	Yes
Resilience bond	Resilience bonds are fixed-income securities that raise capital for projects that strengthen climate resilience (resilience projects). A bond issuer estimates the risk reduction benefits resulting from a resilience project. The investors' reduced risk to lose the principal is translated to reduced premiums to be paid by the bond sponsors (who pay premiums in return for a contingent payment in the case of a pre-defined event). Resilience bonds monetize avoided losses through a resilience rebate (the insurance savings), which funds the resilience project[66].	The Yuba River Watershed forest resilience bond raised private capital for forest restoration; The Miami Forever Bond raised capital for coastal flood protection, including mangrove conservation and restoration.	Yes
Catastrophe bond* with nature-based risk reduction conditions	Catastrophe bonds are securities that raise capital for damage claim compensations following disasters. They allow governments or utility companies to transfer their risk related to natural hazards to investors. When a government signs a cat bond agreement with an international development bank (IDB), it pays a fixed premium in return for a payout triggered by pre-defined threshold. By issuing a bond, the IDB transfers the risk to bond investors. Investors earn a coupon that consists of a risk margin (the client's premium payment) and a funding margin (paid by the IDB). Payouts reduce the bond principal. At maturity, the IDB pays the remaining principal to the investors[67].	A cat bond for liabilities liked to wildfire risk combined with ecological forestry activities could reduce the losses due to wildfires. The first-ever wildfire cat bond issued in California in California in 2018 led to the company's bankruptcy[39], highlighting the challenge of pricing a cat bond and the potential to use NBS to reduce the expected losses.	Yes

Table 1 (continued) | Nature-positive risk transfer and financing instruments (for more details and references, see Supplementary Table 15)

CRTFI	Definition	Example	Implementation ongoing or completed
Debt-for-nature swaps*	Debt-for-nature swaps, debt-for-climate swaps, and debt-for-ocean swaps, also referred to as debt conversions, are instruments that allow debt holders to exchange their debt with commitments for nature conservation, climate action, and marine conservation, often on preferential terms.	Debt-for-nature swap in Jamaica (1991), the Seychelles (2015), Belize (2021), Ecuador (2022), Barbados (2022), and Gabon (2023)	Yes
Micro-loan/credit line* to fund NBS	Loans/credits to fund NBS are debt instruments that provide financial capital to borrowers who have to repay the capital with interest. Green credit lines can be used by financial institutions to promote investments in NBS.	Triodos Groenfonds' conversion loans for sustainable farming; Indonesian Credit Union Semandang Jaya loans for integrated landscape management and sustainable agribusinesses	Yes
Debt facility* for NBS	A debt facility to finance NBS projects provides direct or intermediated loans or invests in equity funds.	Dedicated debt facility for natural flood management in the Wyre River Catchment, UK	Yes
Asset-backed security* for NBS project	An asset-backed security (ABS) is a debt instrument that is based on an asset pool with multiple assets that generate a cash flow from debt. The ABS is structured in the form of bonds or notes, providing fixed income over a predetermined time period. First, companies sell their loans or other debt to a financial institution. Second, the financial institution consolidates multiple loans (the assets) into an ABS - a process known as securitization - and sells the portfolio of assets to investors[68].	In China, ABS were used to mobilize the rights to receive water service fees in the context of wastewater treatment projects. Similar approaches could be developed for NBS.	No
Credit enhancement instruments			
Construction all risks insurance for NBS project	Construction all risk insurance policies typically covers risks related to construction projects. Such an insurance can also cover risks related to the realization of an NBS project.	Construction all-risks policy for a nature-based coastal protection project on Texel Island	Yes
Full or partial credit guarantee for NBS project	A (partial) credit guarantee is an agreement in which a third party promises to repay a debt (or a part of it) should the borrower be unable to pay, regardless of the reason of default. Guarantees can be given for different debt instruments (like loans or bonds) from private lenders[26]. A government guarantee reducing the risk of negative returns can encourage private investors to acquire green bonds[54].	Sustainable Landscape Guarantee Program in India provides partial credit guarantees to local financial institutions to de-risk their investments in NBS projects	Yes
Guarantee/fund/ political risk insurance for green bond defaulting	(Partial risk) Guarantees, funds, or political risk insurance can cover risks that occur when a private actor lends to sovereign or subsovereign borrowers. Political risks are sovereign or sub-sovereign risks like "currency inconvertibility, repatriation, expropriation, political force majeure such as war, regulatory risk and government payment obligations (such as tariffs)"[26].	Guarantee provided for Seychelles' blue bond; Political risk insurance for the Belize blue bond; endowment fund for the Gabon debt-for-nature swap and blue bond	Yes
Catastrophe wrapper for debt instrument that funds NBS	A catastrophe wrapper (or 'cat wrapper') is an insurance policy that covers a government's bond repayments to investors in the event of a disaster that is likely to result in the government's defaulting on repayments. The instrument lowers the risk of a government not being able to repay a green or blue bond and hence improves the credit rating. It allows the government to access funds through debt instruments with better interest rates for investment projects, including NBS projects. A parametric insurance trigger is set at the hazard intensity that causes the government to be unable to repay the bond.	Belize's debt-for-nature swap, blue bond and catastrophe wrapper (2021) by Willis Towers Watson and Munich Re, which takes the form of a parametric insurance policy that covers the government's repayments of a blue bond after hurricanes of a pre-defined intensity	Yes
Performance-based instruments (also called pay-for-performance, pay-for-success, or payments-for-results instruments)			
Environmental impact bond*	Environmental impact bonds are green bonds where the yield is directly tied to the performance of environmental projects[51]. Contracting parties pay for or are paid for environmental services based on pre-defined outcomes[69]. Impact bonds are based on the starting point that outcome payers have a financial interest in an outcome, e.g. an investment in the restoration of wetland to reduce flood risk, but no capacity to retain the risk related to the investment. By signing an impact bond agreement, the outcome payers transfer their risk to private investors[70].	Washington D.C.'s environmental impact bond with a three-tier performance structure to finance a 25-acre green infrastructure installation to store and infiltrate runoff into Rock Creek and reduce the volume of combined sewer overflows that pollute the waterways	Yes
Payments-for-ecosystem-services (PES) combined with other instruments*	Payments-for-ecosystem-services are "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management"[71]. Combining multiple CRTFIs such as PES or insurance with green bonds can be useful to increase resources available for NBS projects[54].	Green bond projects can generate monetizable ecosystem services through PES, which in turn create revenue and make the green bond more attractive to private investors[54].	No

Table 1 (continued) | Nature-positive risk transfer and financing instruments (for more details and references, see Supplementary Table 15)

CRTFI	Definition	Example	Implementation ongoing or completed
Stackable payments-for-ecosystem-services*	Stackable payments-for-ecosystem-services (PES) build on the fact that most NBS deliver multiple ecosystem services at a time and benefit multiple stakeholders. These mechanisms bundle payments for multiple ecosystem services that benefit different stakeholders. Multiple beneficiaries can be translated into multiple revenue streams for PES programs[72].	An example of an NBS project financed by beneficiaries of multiple ecosystem services exists, even though it is not titled a (stackable) PES scheme – and was therefore not classified as such in the inventory. In the Medina del Campo aquifer in Spain, a tourist tax to visit recovered wetlands for bird watching is combined with a water user fee paid by farmers to fund agricultural NBS[55].	No (one project, which was not titled as stackable PES but could be considered as such was in the process of implementation)
Environmental cash-for-work programs*	An environmental cash-for-work program compensates individual participants for their work in NBS projects. They create financial incentives for ecosystem conservation and restoration.	Environmental cash-for-work programs for mangrove restoration in the Philippines	Yes
Agri-environmental schemes			
Conservation easement	Conservation easements prescribe a permanent land-use restriction or conservation requirement that the landowner agrees to voluntarily in exchange for a government payment.	In the U.S., there were over 221,000 conservation easements protecting about 38 million acres of land, as of December 2, 2024[73].	Yes
Fallowing agreement	Fallowing agreements are contracts through which farmers agree to temporarily provide their land - to use its floodwater storage capacity or to make available water that would be needed for irrigation for other uses - in return for a compensation.	Agricultural fallowing agreement for temporary land conversion in the U.S.	Yes
Cropland retirement program	Cropland retirement programs provide farmers with a stable income stream for removing erodible land from production.	Conservation Reserve Program under Title XII of the Flood Security Act of 1985 in the U.S.	Yes
Tax benefits for conservation agriculture	Tax reductions for farmers who practice conservation agriculture are an instrument to incentivize NBS.	The conservation stewardship tax exemption in Illinois is granted to farmers with an approved conservation plan and in Iowa, in the U.S., tax credits or exemptions are granted to owners of native and open prairie land[74,75].	Yes
Equity instruments: actively managed funds			
Water fund*/Upstream-downstream compensation fund	A water fund or upstream-downstream compensation fund establishes a mechanism in which beneficiaries of hazard reduction contribute capital to the fund while those providing the hazard regulating services are compensated. One example is that farmers upstream who provide their farmland for flood water storage receive fund resources and governments of cities downstream (or their residents) capitalize the fund[76]. Compensation funds can be a mechanism that leverages market-based equity investments in NBS[77].	Quito water fund in Ecuador; Lima water fund in Peru; Xin'an River ecological compensation fund in China; French basin-wide compensation funds established by local water management institutions	Yes
Prescribed fire catastrophe fund	A catastrophe fund for liabilities linked to prescribed fires could provide fast payouts to compensate for the damages caused by escaped prescribed burns.	In California, in the U.S., Senate Bill 170, the Budget Act of 2021, included USD 20 million to create a Prescribed Fire Claims Fund to cover losses from non-public entities.	Yes
Disaster risk reduction fund financed by insurance premiums	Disaster risk reduction funds that cover nature-based interventions for hazard regulation can be capitalized by insurance premiums. In this way, insurers, as indirect beneficiaries of NBS for risk reduction, can support investments in NBS.	The French Barnier Fund which funds disaster risk reduction measures is capitalized through an additional premium linked to motor vehicle and home/business insurance.	Yes
Market instruments: resilience and carbon credits			
Resilience credits	Resilience credits are measurable, verifiable hazard reductions achieved through nature-based interventions. The methods to quantify flood protection benefits of mangroves could be used to establish resilience credits for coastal wetland restoration and management projects, similarly to carbon credits for climate mitigation[4]. Dual-benefit carbon and resilience credits could be sold at a higher price than pure carbon credits[41].	In Washington, D.C., the Department of Energy and Environment (DOEE) established a city-scale stormwater retention credit system. A regulation adopted in 2013 made green design elements (like green roofs) to minimize stormwater runoff compulsory for developments larger than 5000 square feet. Developers must meet 50% of the target on their property, while the remaining 50% can be achieved by buying DOEE certified stormwater retention credits from others who voluntarily built green infrastructure. DOEE offers to buy the credits at a price below the market price. This encourages sellers to sell the credit on the market, while giving them certainty that they will get some returns when the demand is low[78].	Yes
Carbon credits to fund NBS	Carbon credits could be used to finance the implementation of NBS. For example, restoring a mangrove forest could provide carbon credits that, when sold, can finance additional NBS.	The social enterprise Restoration Insurance Service Company (RISCO) was originally set up to offer carbon credits in combination with nature-positive resilience insurance, however they updated their business model (see Suppl. Information)[79].	No

Table 1 (continued) | Nature-positive risk transfer and financing instruments (for more details and references, see Supplementary Table 15)

CRTFI	Definition	Example	Implementation ongoing or completed
Insurance for resilience and carbon credits	Insurance for resilience and carbon credits could de-risk investments in these credits by providing immediate resources to restore ecosystems in case of damage.	In 2016, the UK broker Howden launched an insurance product that covered verified carbon credits. No product exists for resilience credits.	No (for resilience credits)/Yes (for carbon credits)
Forest carbon offset buffer pool to protect NBS and carbon credits against risks	A forest carbon offset buffer pool is a self-insurance mechanism against various risks that could reverse forest carbon storage.	The California forest carbon offset buffer pool is capitalized by contributions from carbon offset projects. Up to 19% of the carbon credit value is paid into the fund, with wildfire risk accounting for 2–4% and other natural hazards for 3%. The contribution is lower when wildfire hazard mitigation practices are employed.	Yes

Some CRTFIs are broader financial instruments that can support NBS for climate resilience among a range of use cases; those are marked with an "*" in the first column. The fourth column indicates whether the CRTFI type has been implemented or implementation is currently ongoing ('Yes') or in the conceptual phase ('No'), meaning that at the point of concluding the review, no such CRTFI type has been implemented (for a detailed overview of the project status at publication, see Supplementary Fig. 3).

accounting for about 30% of all projects found in the review (Fig. 2d). In this section, we present these instruments in more detail, along with notable example projects – the Quintana Roo reef (and Mesoamerican reef) insurance and the U.S. National Flood Insurance Program (see pattern in Fig. 2d) – to illustrate how nature-positive insurance mechanisms can work.

Ecosystem insurance is defined as "a contract, in which a policyholder pays a fixed amount (the premium) to an insurer in exchange for reimbursements to restore a natural asset (e.g. coral reefs) following a covered event (e.g. a tropical cyclone)" (Supplementary Table 15). Ecosystem insurance has been provided through parametric products, an increasingly used tool for simple and rapid insurance payouts based on pre-defined thresholds. An overview of these products is presented in Table 2. The first ever reef insurance – launched in Quintana Roo, Mexico, in 2018 – is the most frequently cited ecosystem insurance. It is often highlighted as a role model for nature-positive CRTFI (Figs. 2d and 4). It pioneered the mobilization of funding for post-disaster nature restoration through insurance from multiple sources, including federal and tourism taxes[37]. A complementary initiative, the Mesoamerican reef insurance, launched in 2021, is the second most mentioned example of ecosystem insurance and the only example of regionally pooled risks to reefs. Regional disaster risk pools, like the African Risk Capacity, allow countries to pool their diversified and geographically spread risks – but they have not yet entered the nature-positive domain. Jointly retaining and reinsuring ecosystem-related risks is more cost-efficient than national solutions[38].

Ecosystem insurance is suitable when the nature-based protection benefits are sufficiently high and when beneficiaries are willing and able to pay for the insurance, e.g., when reefs protect high-value assets like hotels. However, people particularly vulnerable to climate impacts live in houses with comparatively low economic value. A conventional economic analysis logic would prioritize investments in ecosystems that protect high-income neighborhoods. Two ecosystem insurance products address this issue by applying a nature-positive and people-positive design. They support communities whose livelihoods depend on reefs: The ecosystem livelihoods insurance, launched in 2019 by the Caribbean Ocean and Aquaculture Sustainability FaciliTy (COAST) initiative, with 3-year policies in Grenada and Saint Lucia, and the Fiji ecosystem insurance, launched in 2024[39,40].

The other most documented CRTFI did not have a consistent terminology in the literature (Fig. 2d). We coined the term *Nature-Positive Resilience Insurance* (NPRI) to help bring consistent terminology to insurance schemes that grant the policyholder a premium discount in return for hazard-regulating nature-based interventions (Table 1 and Supplementary Table S15). The term builds on the broader 'resilience insurance' that grants a policyholder a premium discount in return for investments in risk reduction[41]. The insurance industry uses the term 'resilience risk transfer' to describe such instruments[42]. The most prominent example of NPRI, the U.S. National Flood Insurance Program, grants a discount to all policyholders in a community implementing resilience investments like green space preservation (Fig. 5).

Other NPRI products grant a discount at the individual level: Acknowledging that green roofs reduce private property insurance payouts, the Dutch insurer Interpolis offered discounts of up to 7% to customers who install green roofs[43]. In a 3-year pilot, the USDA Risk Management Agency topped up crop insurance subsidies by USD 12 for farmers in Iowa who used cover crops. Researchers suggested "a sliding scale of crop insurance premiums" relative to conservation efforts[44,45].

Several publications report that nature-positive resilience insurance is economically viable. A hypothetical case study in a coastal region estimates that insurance premium reductions in the first 5 years could cover 44% of reef restoration costs[46]. A levee setback, the relocation of a levee further away from the river channel to create additional space for the natural floodplain, along the Missouri River in the U.S. could reduce flood insurance premiums by 55%, while generating biodiversity benefits and water quality improvements[47]. Similarly, ecological forestry in Placer County, in the northern Sierra Nevada, in the U.S., could lower home insurance premiums by 40% on average in the *North Fork American River subbasin* and by 52% in the Foresthill community, where premiums are higher than the basin-wide average premiums[48]. Despite the evidence of their economic viability, these schemes have not yet been used at scale.

Effectiveness of nature-based solutions supported by CRTFIs

After taking stock of the two most documented instruments, we assessed the evidence on the effectiveness of NBS supported by nature-positive CRTFIs based on three dimensions: (1) quantification of hazard regulation, an ecosystem service particularly relevant to NBS for climate resilience, (2) reporting of other NBS co-benefits, measured as ecosystem services and the broader social and ecological outcomes of the NBS; and (3) economic appraisals.

The NBS' hazard regulation benefits are not quantified for over two-thirds (69%) of the projects in the reviewed literature. A monetary valuation of hazard regulation benefits was presented for one-quarter of the projects (Fig. 6b). This includes a large share of publications reporting the benefits found in previous studies, without conducting any benefit analysis. Most projects rely on previous studies to quantify the hazard regulation benefits (Supplementary Fig. 11).

Nature-based interventions are not compared to alternatives in 59% of the academic publications. They are rarely compared to engineered (16%), other nature-based (13%), non-structural (5%), and hybrid (4%) interventions. Among the 25 academic publications that compared NBS to a non-nature-based intervention, 40% mentioned that NBS were more effective than the non-nature-based intervention (Fig. 7).

Probabilistic analysis is only conducted in a small fraction of projects (8%) to assess the NBS' hazard regulation benefits (Supplementary Fig. 12). NBS for hazard regulation were found to be especially efficient in avoiding losses and damage in relative terms during low-intensity events[5].

Uncertainty in the valuation of the NBS' hazard regulation benefits is not accounted for in most cases (76%), and outcome equity (reflected in the

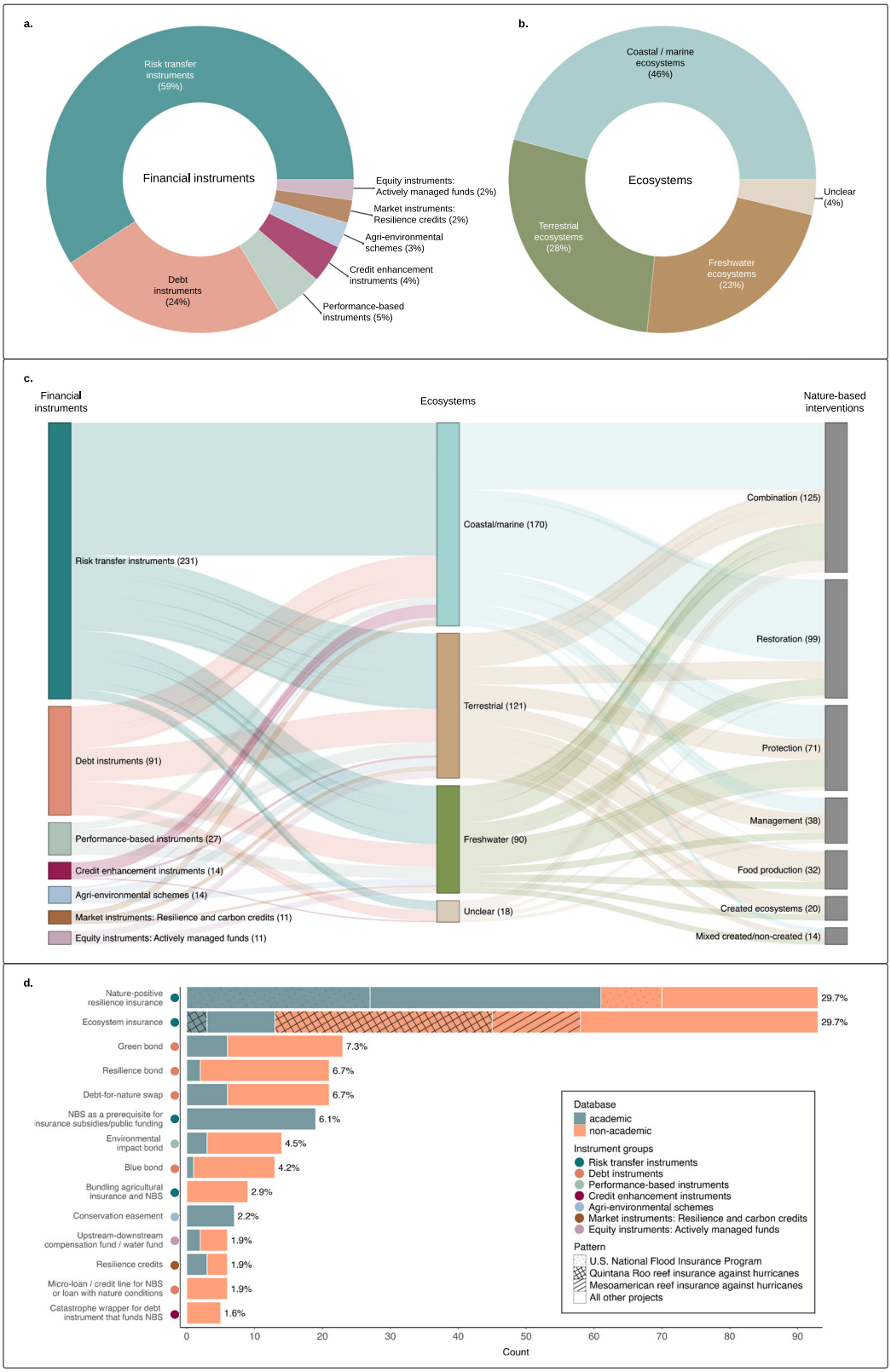


Fig. 2 | Nature-positive climate risk transfer and financing instruments (CRTFI). **a** Distribution of CRTFI categories among all identified nature-positive CRTFIs ($n = 372$; note that a single project can involve multiple CRTFIs). **b** Distribution of ecosystem categories supported by CRTFIs across all identified ecosystems ($n = 485$; projects can target multiple ecosystems). **c** Integration of CRTFIs across ecosystems and interventions: Each project ($n = 313$) may combine multiple instruments, ecosystems, and interventions. **d** Most frequently occurring nature-positive CRTFI: instruments used in at least five projects. The percentage on the right of each bar indicates the share of total projects ($n = 313$) in which that CRTFI appears. The colors of the points on the y-axis represent the CRTFI category. The colors of the bars indicate the database where the publication was found that reported about the project. The most frequently reported projects are highlighted with a pattern; all other projects have no pattern.

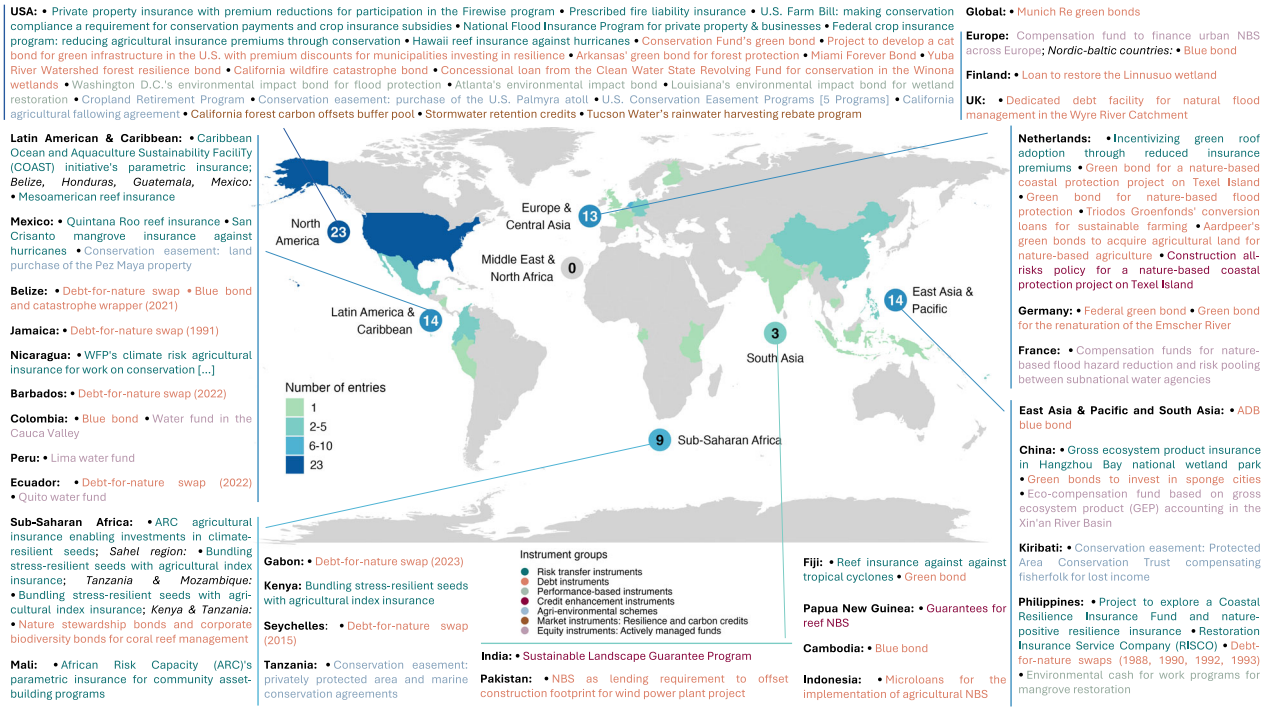


Fig. 3 | Global inventory of nature-positive climate risk transfer and financing instruments. The map shows the number of inventory entries per country, considering projects at the national level and below. The count of entries per global region (considering instruments at all levels, including the regional level) is presented in bold. The inventory contains one entry at the global level that is not displayed on the map. ADB blue bonds are counted twice (for 'South Asia' and 'East Asia and Pacific'). The frame presents the names of nature-positive CRTFIs in the inventory, color-coded per instrument group.

disaggregation of benefits by socioeconomic groups) is not reported in the majority (58%) of projects that quantify the NBS' hazard regulation benefits (Supplementary Figs. 13, 14 and Supplementary Note 1). When benefits are not disaggregated, it is unclear who benefits.

In contrast to gray infrastructure, NBS provide a range of co-benefits – in addition to disaster risk reduction – which are not comprehensively reported in the reviewed literature. We assessed nature-positive CRTFI project descriptions regarding their reporting on ecosystem services and social and ecological outcomes of the supported NBS.

Ecosystem services are the benefits people obtain from ecosystems[49], often categorized as regulating (e.g., water quality regulation), provisioning (e.g., food production), cultural (e.g., mental health benefits), and supporting (e.g., soil formation)[50]. Ecosystem services are disregarded in 35% of the nature-positive CRTFIs identified in this review (considering all stages, from the conceptual stage to project conclusion). Cultural, spiritual, and recreational services are the most reported ecosystem services (mentioned in 39% of all projects), followed by provisioning services (35%). Benefits for human health are largely neglected in the reviewed publications (reported in only 4% of all projects) (Fig. 6a). Supporting services, including biodiversity benefits, are mentioned in 30% of projects presented in non-academic publications but only in 7% of academic publications. Climate regulation benefits are mentioned in 30% of academic and 17% of non-academic projects.

Most academic studies on nature-positive CRTFIs only briefly mention ecosystem services without quantitatively or qualitatively describing them, let alone monetizing them (Fig. 6b, c). For nature-based interventions to qualify as NBS, they need to provide positive social and ecological outcomes[2]. Social outcomes refer to an intervention's impact on people; ecological outcomes refer to its impact on "species conservation or the quality, diversity, or resilience of natural ecosystems"[6]. Social outcomes are reported in 10% and ecological outcomes in 19% of the academic publications (Fig. 6d).

After evaluating the evidence on co-benefits of NBS supported by CRTFIs, we examined the reporting of economic evaluations. An economic appraisal is presented for about a quarter of projects and assessments. Ecosystem service monetary valuation (47%) and cost-benefit analysis (35%) are the most frequently used approaches for economic appraisals, followed by cost-effectiveness analyses (8%) (Supplementary Fig. 15).

Economic appraisals as part of monitoring and evaluation during and after project implementation are rarely reported, even though these are the stages where instruments could be improved and lessons for future projects could be learned. Of the 50 projects in non-academic publications for which economic appraisals were reported, the majority (82%) were in the project design phase, some (16%) were under implementation, and one project (2%) was concluded. Most appraisals assessed only the economic viability of the NBS (82%), while fewer appraisals assessed the nature-positive finance instrument (16%) or only the finance instrument, independently of the NBS (2%). This finding indicates that, when nature-positive CRTFIs are implemented, evaluations tend to focus on the economic viability of the supported NBS, while giving limited attention to the financial performance or functioning of the instruments themselves. Evidence on the benefits and actual costs of NBS supported by CRTFIs is limited, with little impact reporting from post-project evaluations. For risk transfer instruments and bonds, data like payout amounts, bond volume, interest rates, and occasionally the geographical coverage or number of beneficiaries were reported. In contrast, the impacts of other CRTFIs were rarely published. Given the diversity of CRTFIs and contexts, tailored monitoring and reporting are needed. Transparent, stakeholder-oriented evaluation is essential for scaling NBS finance, as emphasized by previous research[18–20,51]. However, effectiveness reporting remains a key evidence gap, which may hinder the broader adoption of nature-positive CRTFIs.

Discussion

In this systematic review, we structured the evidence on nature-positive CRTFIs identified by screening over 3000 academic publications and 78

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Table 2 | Overview of parametric ecosystem insurance products

Launch	Location	Hazard (trigger)	Ecosystem	Stakeholders involved in product development and financing	References (selection)	Focus
2018	Quintana Roo, Mexico	Hurricane (wind speed)	coral reef	*Policyholder:* Government of Quintana Roo; *(Re)Insurer:* Swiss Re; *Other stakeholders involved:* Coastal Zone Management Trust (CZMT), The Nature Conservancy, National Commission of Protected Areas (CONANP), and Cancun Hotel Owners Association	80–83	Reef restoration
2019	Grenada and Saint Lucia	Adverse weather (cumulative modeled losses from waves and rainfall at the end of the policy year), cyclone (modeled losses due to wind and storm from the cyclone footprint)	Coral reef	*Policyholder:* Governments of Grenada and Saint Lucia; *Technical assistance*: World Bank and Caribbean Ocean and Aquaculture Sustainability FaciliTy (COAST) initiative; *Financial support*: U.S. State Department, Caribbean Catastrophe Risk Insurance Facility (CCRIF), and the Caribbean Regional Fisheries Mechanism (CRFM)	39, 40*, 84*	Reef restoration & livelihood support
2021	Mesoamerican reef in Belize, Honduras, Guatemala, Mexico	hurricane (wind speed)	Coral reef	*Policyholder:* Mesoamerican Reef Fund (MAR Fund); *(Re)Insurer and broker:* AXA Climate, Munich Re, and Willis Towers Watson (WTW); *National lead entities:* Mexico: National Commission of Protected Areas; Belize: Fisheries Department; Honduras: Instituto de Conservación Forestal, Áreas Protegidas y Vida Silvestre; Guatemala: unclear; *Financial support:* Ocean Risk and Resilience Action Alliance (ORRAA), InsuResilience Solutions Fund, funded by KfW Development Bank on behalf of the German government, Canadian Government, United Nations Development Programme (UNDP), and Central American Commission on Environment and Development	38, 85*, 86*, 87, 88	Reef restoration
2022	Hangzhou Bay National Wetland Park, Ningbo City, Zhejiang province, China	Typhoon, drought (based on agricultural damage functions and GEP accounting[77])	Gross ecosystem product (GEP), measured by carbon sink and wetland maintenance and restoration cost	*Project partners:* Ningbo City Wetland Protection Authority, Swiss Re, China Pacific Insurance Company, a local Chinese insurer, Agricultural Bank, third-party agencies, and the local government	89–91*	Wetland restoration
2022	Hawaii, USA	Hurricane (wind speed)	Coral reef	*Project partners:* The Nature Conservancy and Munich Re; *Financial support:* Bank of America Foundation and Howden Group Foundation	41, 92, 93	Reef restoration
2024	Lau islands, Fiji	Tropical cyclone (wind speed, cat-in-a-circle policy)	Coral reef	*Policyholder:* Vatuvara Foundation; *Broker:* Willis Towers Watson (WTW) and Insurance Holdings (Pacific) Pte Ltd.	94, 95*	Reef restoration & livelihood support
Under development[a]	San Crisanto, Yucatán, Mexico	Hurricane (tbc)	Mangrove forest	*Planned policyholder*: San Crisanto community (consisting of about 150 families); *Project partners:* AXA Climate, AXA México, and ClimateSeed	96*, 97	Mangrove restoration (community receives the payout)
Under development[b]	Gili Matra Islands, West Lombok, Indonesia	Climate hazards (tbc)	Coral reef	*Project partners:* Indonesian Government and UNDP; *(Re)Insurer:* Swiss Re and Indonesian insurance industry association; *Financial support:* The UK's Blue Planet Fund	98*	Reef restoration & livelihood support

References highlighted with a star (*) are references in addition to the screened material. | For details on the various parametric models including a pure parametric policy (e.g., in Quintana Roo, Mexico), a gridded parametric or "cat-in-nested-circle" policy (e.g., used in the Mesoamerican reef for the 2021 Atlantic hurricane season and in Fiji); and a parametric index (used in the Mesoamerican reef for the 2022 Atlantic hurricane season) see Whaton[38] and Pacific Catastrophe Risk Insurance Company[95].

[a]A partnership for product development was announced in December 2023 and renewed in December 2024.

[b]The project partners are collaborating since 2022 to develop a product and the development of a long-term premium funding model for the Indonesian government is ongoing.

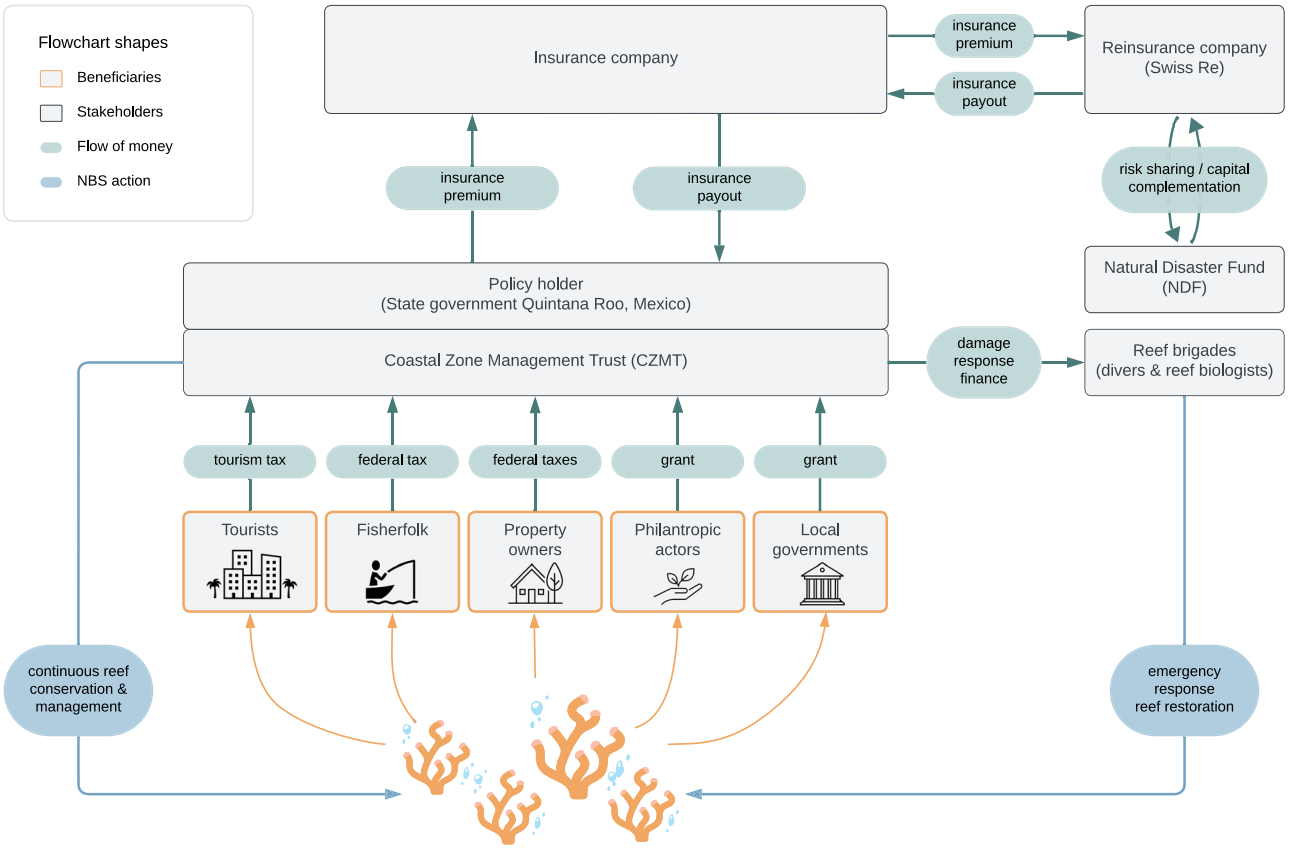


Fig. 4 | Visualization of the reef insurance in Quintana Roo, Mexico. Adapted from Visser et al.[83] with permission. In 2018, The Nature Conservancy, the Quintana Roo State Government in Mexico, and the Cancún and Puerto Morelos Hotel Owners Association signed an agreement to establish a Coastal Zone Management Trust (CZMT). The CZMT continuously conserves and manages the reef and beaches. In collaboration with the State government of Quintana Roo, the Trust collects capital from various beneficiaries. It receives the reef insurance payouts and pays previously trained reef brigades that restore the reef after a hurricane. Reinsurance is provided by Swiss Re (copyright of icons: Iconbuddy 2025).

non-academic databases. We confirmed an increasing interest in CRTFIs, highlighted by 235 selected publications and 313 projects focused on nature-positive CRTFIs. The rise in attention from 2019 corresponds to the publication of the first IPBES 'Global Assessment Report on Biodiversity and Ecosystem Services'[52] and the international climate conference (COP25) decision of the Standing Committee on Finance to make financing NBS the topic of its 2020 Forum[53].

This review does not aim to measure or evaluate the effectiveness of NBS directly, as such assessments are not systematically reported in the literature. Instead, we analyze how effectiveness is reported, discussed, or approximated in the literature. While this does not allow for definitive conclusions about performance, the frequency of reported benefits or outcomes offers preliminary directional insights. For instance, the consistent association of CRTFIs with flood, cyclone, and erosion risk reduction may signal areas where NBS are perceived as especially impactful. At the same time, the lack of consistent measurement highlights the need for more systematic evaluation and reporting of NBS effectiveness in future studies.

While the literature primarily highlights two instruments (ecosystem insurance and NPRI), we identified opportunities for blended and understudied CRTFIs, which are summarized in this section. We found a great diversity of CRTFIs with 33 distinct CRTFIs (Table 1). The inventory can serve as a tool for identifying potentially relevant CRTFIs, and examples can be used for replication, scaling, and adaptation in other geographies. The breadth of instruments in the inventory allows investors and decision-makers to identify suitable instruments based on their needs. CRTFIs require collaboration across stakeholder groups and a conducive legal and regulatory framework, which may limit the adoption of some CRTFIs. Overemphasizing a few instruments risks promoting solutions that may not be suitable across different contexts.

Notable examples of understudied CRTFIs include environmental impact bonds, resilience bonds, and resilience credits. These instruments share the characteristic that, like NPRI, they monetize avoided losses resulting from the NBS' hazard regulation. The monetization of resilience investments allows those investing in nature (and climate resilience) to amortize their investment through premium discounts or resilience credit revenues (Fig. 5).

While coral reefs (included in 28% of all projects) are the ecosystem that has received the highest attention in the CRTFI literature, other ecosystems where NBS have a high potential to reduce climate-related hazards, like inland wetlands (9%), agricultural land (12%), and urban areas (12%), have received less attention.

Each CRTFI has distinct strengths and addresses different risks and financing needs. This highlights the opportunity to further explore blended CRTFIs that combine multiple CRTFIs. Combining green bonds with payments for ecosystem services (PES) could generate revenue and attract private investors, especially when the PES income alone cannot cover the full cost of the NBS project[54]. Such blended CRTFIs may also involve insurance. For instance, a green bond enables afforestation on degraded grassland, which reduces the flood hazard. In return, the bond issuer receives insurance premiums from a nearby hydroelectric plant and PES payments from downstream communities. The bond premium is tied to flood risk – higher risk results in higher premiums, paid by the issuer to the bond buyer[54]. Multi-layered financial protection strategies that integrate multiple CRTFIs are needed to address risks of different intensities and frequencies.

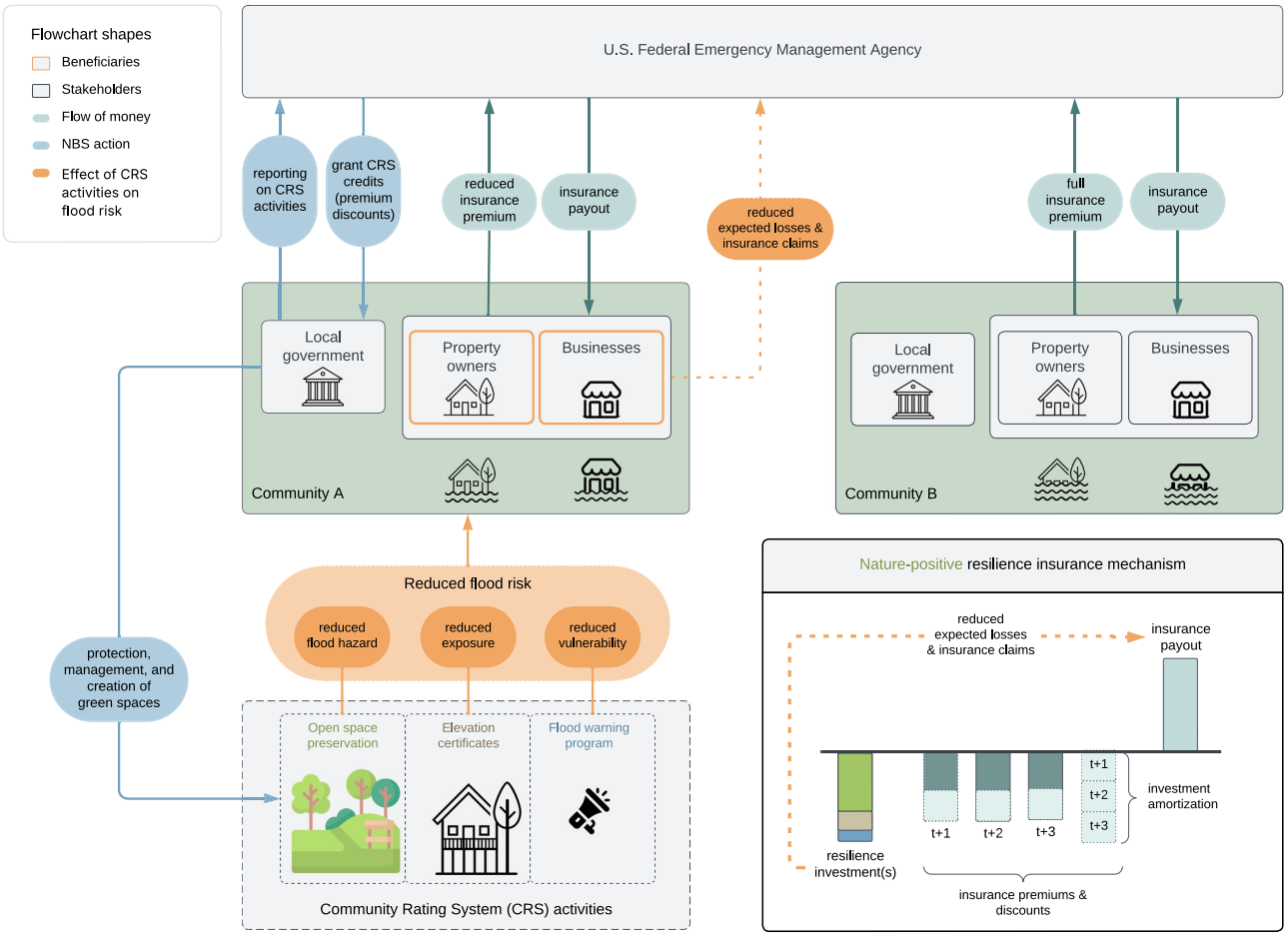


Fig. 5 | Visualization of the U.S. National Flood Insurance Program's Community Rating System's discounts for green space preservation. Under the U.S. National Flood Insurance Program's Community Rating System, the Federal Emergency Management Agency offers discounts to communities that implement flood risk reduction (like open space preservation to protect natural floodplain functions) and preparedness measures (box at the bottom left). Community Rating System activities reduce the flood risk, expected losses due to flooding, and resulting insurance claims (orange lines). The agency grants property owners and businesses in the participating communities (Community A) premium discounts. In resilience insurance, the resilience investments (e.g., open space preservation, elevation certificates, and flood warning programs) are amortized by the premium reductions (box at the bottom right based on a conceptual framework by Reguero et al.[46]; figure adapted by Kelso et al.[41] with permission). Nature-positive resilience insurance involves resilience investments in the form of NBS, such as open space preservation to protect or restore the natural floodplain and its functions[100] (copyright of icons: Freepik Company S.L. 2010–2025).

Moreover, CRTFIs that integrate various ecosystem services are uncommon, even though such solutions could benefit diverse stakeholders and combine multiple revenue streams. An example of a stackable PES scheme that incorporates multiple ecosystem services exists in the Medina del Campo aquifer in Spain. A tourist tax for visiting restored wetlands and a water user fee from farmers jointly fund agricultural NBS[55]. One publication suggested dual-benefit carbon and resilience credits, which could be sold at a higher price than pure carbon credits[41].

While this review makes various contributions to the literature, it has some limitations. This review focuses exclusively on nature-positive CRTFIs, excluding other mechanisms that could play a role in scaling investments in NBS. Regulatory policies, repurposing of agricultural and fisheries subsidies, environmental commitments by insurers and investors, financial risk disclosures, and private investment mobilization strategies were not included in this review.

While reviewing both the academic and gray literature, this review should still be considered a subset of the evidence. The scope is limited to nature-positive financial instruments that enhance climate resilience – we may have missed other innovative nature-positive blended finance instruments that do not focus on climate resilience. There is a risk of publication bias, as successful or high-profile CRTFI projects are more likely to be documented, while unsuccessful or abandoned initiatives may be underreported. The overrepresentation of academic and formal institutional sources means that innovative, grassroots, or smaller-scale CRTFI initiatives – especially in the Global South – may have been missed. The review was also limited to English-language publications, potentially excluding relevant CRTFI examples that are documented in other languages.

Finally, many sources lacked methodological transparency, making it difficult to assess the rigor and reliability of the economic analysis conducted, or if such analysis was even conducted. There were gaps in data accessibility, especially for private-sector financial instruments where proprietary data may not be publicly disclosed.

The literature primarily emphasizes the potential of nature-positive CRTFIs, but it also highlights several potential risks and pitfalls. First, debt instruments and related austerity measures could deepen global inequality. One study suggests that debt-for-nature swaps commodify nature without addressing the root causes of debt in the Global South. Additionally, the authors raise concerns about conservation organizations acting as creditors and asset managers and exerting influence over local marine ecosystems[56].

Second, insurance can exacerbate social inequality. The U.S. National Flood Insurance Program's Community Rating System has been criticized for disproportionately affecting lower-income households - due to increased housing costs (resulting from green space creation or higher building codes) and relocation of mobile home parks for land acquisition - while benefitting

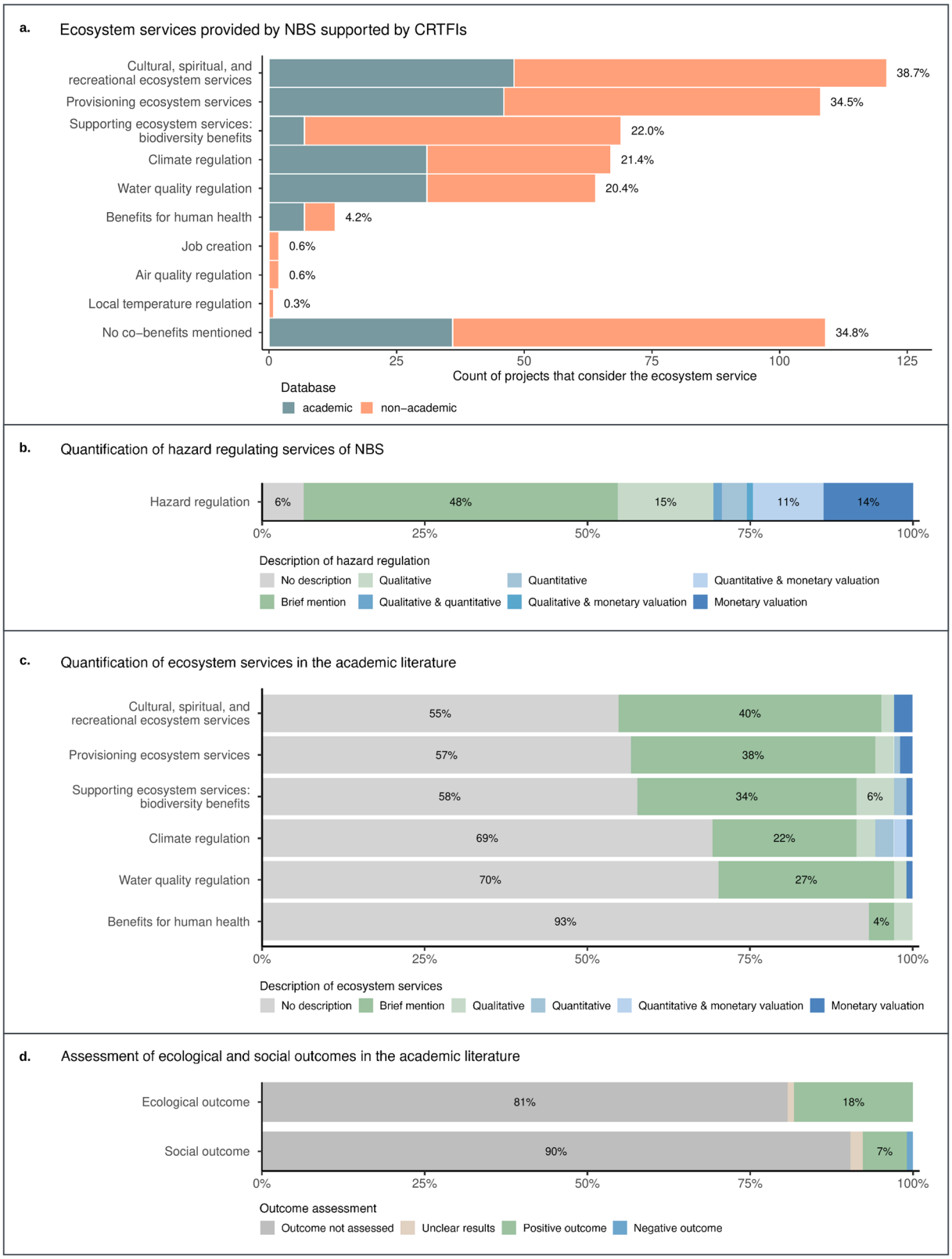


Fig. 6 | Quantification of ecosystem services and outcomes of NBS supported by CRTFIs. a Ecosystem services provided by NBS. The panel presents the number of projects mentioning each service, with the percentage of all projects considering the service indicated on the right. **b** Quantification of hazard regulating services of NBS. 54% of the identified projects provide qualitative descriptions or brief mentions of hazard regulating services; 15% provide a qualitative description, and the remaining 31% provide quantitative descriptions and/or monetary valuations. **c** Quantification of ecosystem services in the academic literature. Most ecosystem services are either briefly mentioned or not described at all. Quantification is rare, and monetary valuation is even less common. The NBS' benefits for human health are disregarded in 93% of the publications. **d** Assessment of ecological and social outcomes in academic publications. Ecological outcomes are assessed in only 19% of academic publications, while social outcomes are considered in just 10%. When reported, outcomes are predominantly positive, with very few studies indicating negative impacts. Sample size for the figure: projects in academic publications ($n = 104$) and projects in non-academic publications ($n = 209$). Panels c and d are limited to academic publications.

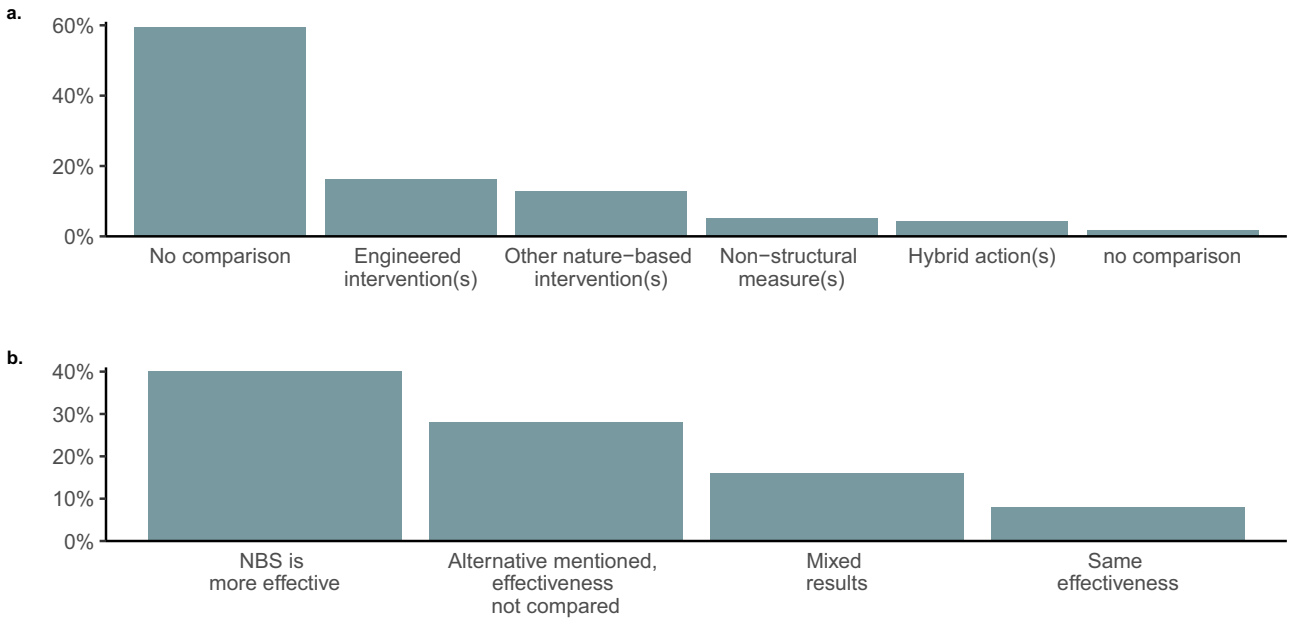


Fig. 7 | Comparison of nature-based intervention supported by a CRTFI with other interventions in the academic literature. a The panel shows the share of academic publications ($n = 104$) per comparator. Most academic publications (59%) do not compare the nature-based intervention to other interventions. Sample size: academic publications. **b** 40% of the academic studies that compare the nature-based intervention with a non-nature-based intervention ($n = 25$) reported that the NBS was more effective. These statistics include estimates by the authors and references to other studies.

wealthy households with premium discounts[57]. Another study emphasized that if designed without a gender-sensitive approach, agricultural insurance can increase gender-based inequality related to land rights and financial inclusion[58].

Third, insurance subsidies can have unintended consequences. The Community Rating System discounts incentivize construction in high-hazard floodplains, undermining the insurance program's goal of reducing vulnerability in flood-prone areas[59]. Crop insurance may inadvertently contribute to ecological degradation by encouraging the expansion of cropland[60].

Fourth, parametric insurance is not a panacea; basis risk (the discrepancy between insurance payouts and actual losses) remains a concern. While the literature overlooks basis risk, examples like tropical cyclones Karen and Dorian in 2020–2021, which caused considerable losses in Grenada and Saint Lucia but did not trigger COAST insurance payouts, demonstrate the issue[40].

Fifth, the pitfall of greenwashing and oversimplicity in monetizing ecosystem services in complex systems was not found in the literature. Commodification may select species based on their economic utility rather than their ecological importance. Foreign monocultures bringing fast visible results might be prioritized over diverse native species that enhance long-term resilience.

These pitfalls highlight the need to incorporate local knowledge, social and environmental safeguards, and a gender perspective for the success and sustainability of nature-based financial instruments. Scenario planning and future pathway exploration could help anticipate unintended consequences before launching new products. Each CRTFI should be part of a comprehensive financial protection strategy, with continuously refined risk models, as examples of basis risk demonstrate.

The gaps in evidence, the identified understudied CRTFIs, and possible pitfalls led to twelve recommendations for future research, presented in Table 3. This review presented a systematic mapping of risk financing and transfer instruments to support NBS for climate resilience. It identified evidence gaps, outlined future research directions, and featured over 70 instruments that enhance human and ecological resilience to climate impacts. As we reach the midpoint of the UN Decade on Ecosystem Restoration, the project inventory offers policymakers and investors integrated solutions to address the nature and climate crises.

Methods

This systematic review followed the methods described by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 Statement[61]. An overview of 27 reporting items for each element of the systematic review is presented in Supplementary Table 1. In the following, we summarize the methods. Further details are presented in the Supplementary Methods, including Supplementary Tables 1–17.

Eligibility criteria

For an article to be considered in the review, three inclusion criteria need to be met. The article needs to mention (1) a risk transfer or financing mechanism, (2) an NBS, and (3) its hazard regulation benefits. Publications that met each criterion but did not draw a link between NBS and CRTFI were also excluded (see Supplementary Methods).

Information sources

We searched two academic databases (Web of Science and Scopus) for peer-reviewed publications. The databases were last searched on June 19, 2024. Nature-positive CRTFI are also discussed in non-academic publications. We searched 78 non-academic databases of selected stakeholders from March 1 to March 30, 2024, and updated the search for some stakeholders in July 2024. The distribution of authors by gender as well as networks of stakeholders who co-author and co-fund publications on nature-positive CRTFIs are presented in the Supplementary Results (Supplementary Figs. 16–20).

Search strategy

For academic databases, the search terms are structured along three scope elements: risk transfer and financing instruments, NBS, and regulation of climate change-related hazards (Supplementary Fig. 21). The search of academic databases was limited to English publications and the document types of Article, Review Article, Book Chapters, Early Access, Data Paper, and Editorial Material. The search terms for non-academic databases were adjusted depending on the stakeholder group and the available filters. We downloaded only the publications where the abstract complied with the eligibility criteria.

Table 3 | Recommendations for future research

Recommendation	Rationale
Quantifying the benefits of NBS	
Quantify the NBS' hazard regulation benefits and highlight sources of uncertainty	Builds investor trust in nature-positive solutions.
Use probabilistic analyses to estimate the NBS' hazard reduction benefits under different climate scenarios	Improves the accuracy of expected avoided annual loss estimates, considering extreme events of all intensities. Probabilistic analysis shows that NBS are particularly effective at regulating hazards from low-intensity, high-frequency events[5].
Conduct assessments that evaluate the entire range of NBS' benefits	Minimizes the risk of benefit underestimation, and enhances CRTFIs that incorporate multiple ecosystem services and revenue streams. By exploring the integration of resilience, carbon, and biodiversity credits, studies could expedite the development a novel, multi-dimensional credit trading system.
Targeting understudied geographies and types of CRTFIs	
Conduct more research in the Global South	Reduces the bias toward evidence from the Global North in English-language publications, where most authors and most nature-positive CRTFIs evidence are concentrated. Experiencing major climate impacts, the Global South is a region where NBS could help address increasing climate risks.
Further explore solutions that combine multiple CRTFIs	Supports risk-layering approaches in financial protection strategies. For instance, insurance could be complemented by a catastrophe bond in regions with uninsurable risks, such as dry areas with a high wildfire risk or low-lying island nations with a high flood risk.
Investigate the cost-efficiency of regional pooling of ecosystem-related risks	Strengthens the evidence that jointly retaining and pooling ecosystem-related risks across multiple countries or regions improves financial efficiency and resilience. Pooled, geographically diversified risks tied to multiple hazards reduce reinsurance costs compared to single-country coverage. However, proprietary risk models may not be disclosed, limiting the evidence demonstrating these benefits.
Incorporating broader concepts like equity and resilience	
Disaggregate benefits by socio-economic groups and conduct well-being-based risk assessments	Results in more equitable product designs and fosters nature-positive CRTFI tailored to benefit the most vulnerable. Identifying who benefits and who bears the costs is essential to unlocking the full potential of innovative financial instruments for NBS.
Integrate resilience considerations by adopting a socio-ecological systems approach	Recognizes the interdependence of community and ecosystem resilience, fostering the development of nature- and people-positive products. For instance, when fishers lack resources and materials for post-cyclone recovery, they may be forced to use timber from protected mangrove forests to repair their boats. People-positive products integrate livelihood components that directly support community needs.
Scaling nature-positive CRTFIs	
Assess demand for nature-based interventions and CRTFIs	Improves the understanding of what elements at risk matter most to those most vulnerable to climate change and who could invest in nature-positive CRTFIs. Demand can be assessed by analyzing people's preferences and willingness (and ability) to pay for nature-positive CRTFI.
Conduct post-project evaluations to assess the long-term effectiveness and economic viability of NBS supported by nature-positive CRTFIs	Ensures that lessons learned from completed projects inform future initiatives, improving the design and implementation of nature-positive CRTFIs. Most existing economic appraisals occur in the project design phase, leaving gaps in understanding long-term outcomes.
Explore the conditions for nature-positive CRTFI to trigger a positive tipping point	Highlights the potential of nature-positive CRTFI to enact positive tipping points "at which small interventions can trigger self-reinforcing feedbacks that accelerate systemic change"[99]. For example, widespread adoption of resilience credits could trigger a virtuous cycle of protecting and sustainably managing ecosystems that reverts the trend of nature loss.
Refine damage functions for ecosystems and crops	Enables the expansion of ecosystem insurance with a livelihood component from coastal ecosystems (where examples are currently concentrated) to terrestrial and freshwater ecosystems. For example, accurate crop damage models would allow for the scaling of NPRI in the agricultural sector that offers premium reductions in return for nature-based interventions.

Selection process

We conducted the systematic review in Covidence, a web-based collaboration software that allows documentation on the decisions regarding the publication selection in collaborative research projects[62]. We selected 104 (from 3207 screened) academic publications and 131 (from 462 downloaded) non-academic publications (Supplementary Fig. 22).

Data collection

We extracted data from all selected publications in Covidence and realized color-coding of text sections in the reference software Zotero, according to the data extraction template (see Supplementary Methods). The following topics were covered: publication characteristics, NBS (ecosystem, intervention type, hazard), CRTFIs, ecosystem services (considering distributional outcomes and probabilistic methods to quantify hazard regulation benefits), economic appraisal, and other project details. The development of the data items in each category and coding instructions was informed by a review mapping the effectiveness of NBS for climate change adaptation[6] and by the findings from the full-text review of all academic studies. We refined the data collection framework after testing it with five studies. Because many non-academic publications presented multiple nature-positive CRTFI projects, we extracted data for multiple projects from non-academic publications. For academic publications, we only extracted data for multiple projects on an exceptional basis, as they mostly focused on a single project.

Data analysis

The data analysis was conducted in R, a language and environment for statistical computing[63]. We used frequency statistics to synthesize the evidence of nature-positive CRTFIs from the extracted data. Unless otherwise indicated, the statistics provide the percentage or count of projects for which a specific effectiveness measure was reported (as a share of all projects identified in the review). Because NBS and CRTFIs, and their implementation contexts, vary across studies, we did not compare costs, benefits, or economic appraisal results between them. Instead, the focus was on whether (or to what extent) key variables were quantified. The effectiveness of NBS supported by nature-positive CRTFIs was assessed along three dimensions: (1) reporting of NBS co-benefits; (2) quantification of hazard regulation, an ecosystem service particularly relevant to NBS for climate resilience; and (3) economic appraisals.

Data availability

A map showing the projects in the inventory, along with additional data visualizations, is accessible at https://ri-cities.github.io/nbs_finance/. A file including a list of publications from which data was extracted, the data used for the analysis, and the inventory is publicly available[35].

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Author contributions

A.B.W. developed the conceptual framework for the systematic review, conducted the screening and full-text review of the literature, data extraction from the literature, the data analysis, and wrote the manuscript and Supplementary Information. D.L. supervised the project and commented on the manuscript. V.C. conducted the screening and full-text review of the literature and supported the data extraction from the literature. M.R.P. supported the data extraction from the literature. P.H. supervised the project and commented on the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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